INTERNATIONAL SOLDIER SYSTEMS CONFERENCE AND EXHIBITION 2004

Multivariate Anthropometric Models for Soldier System Design, Testing, and Validation

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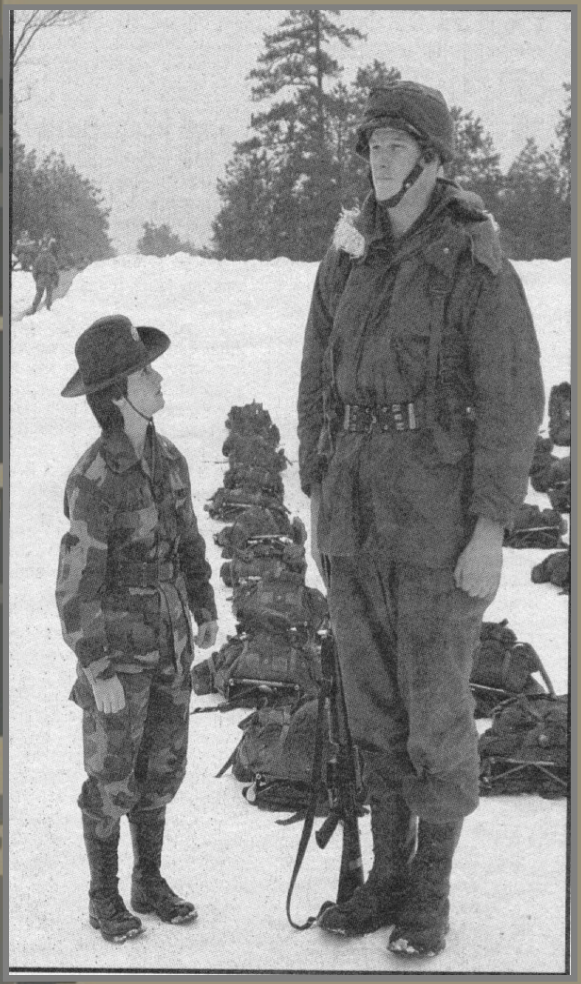
The Science Behind the Warrior: Yesterday, Today and

Anthropometry for the Soldier



- Clothing & Individual Equipme
- Load Carriage Systems
- Airdrop Harnesses
- Workspaces & Workstations
- Aircraft & Ground Vehicle Coc
- Computerized Man-models
- International Standardization

Anthropometric Design Process

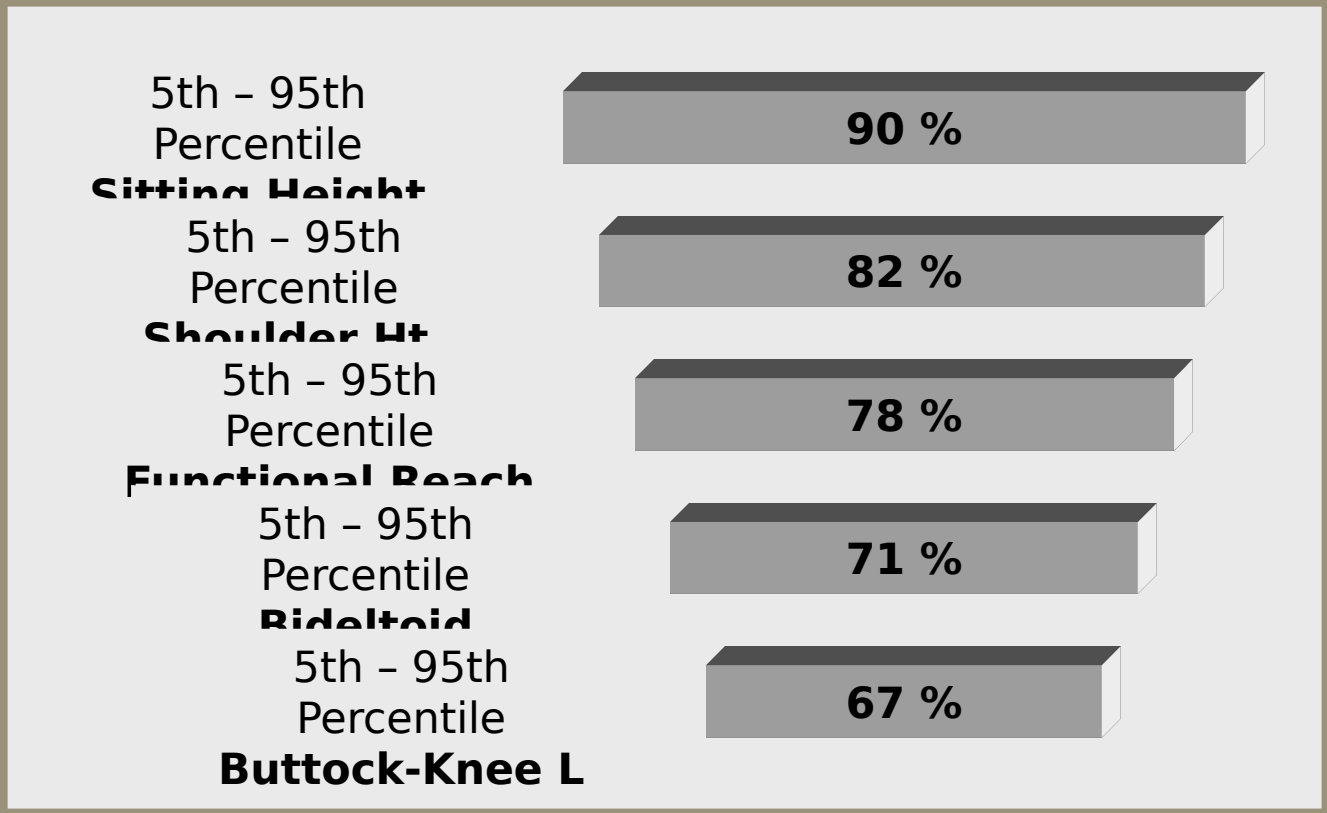
- Measurements ***relevant*** to product design
- Samples ***representative*** of the intended users
- Clearly ***defined*** accommodation targets
- Statistically ***valid*** models of body size variation
- ***Systematic*** application of the anthropometric data
- ***Early and ongoing*** design & sizing evaluations

Deriving Design Values

- **What percentage of users must you fit?**
  - higher rates require adjustability and/or more size categories
  - lower rates influence user performance, safety and satisfaction
  - US Army targets 98% for life support equipment; 90% all other
  - A serious but common mistake: relying on 5th to 95th percentiles

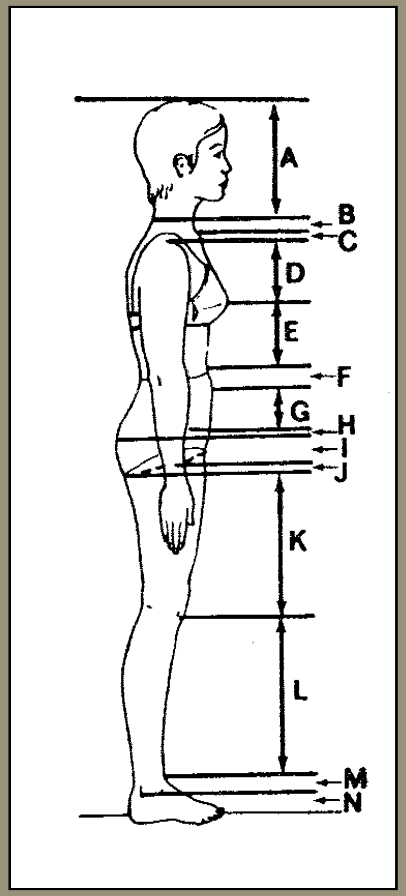
- **Why use multivariate methods?**
  - to ensure valid accommodation rates
  - to identify true “worst case” sizes and shapes
  - to provide additive and proportionally realistic design values

Sequential Reduction in Accommodation Using Percentiles*



** Moroney, WF & MJ Smith (1972). Empirical Reduction in Potential User Population as the Result of Imposed Multivariate Anthropometric Limits. Naval Aerospace Medical Research Laboratory Report, NAMRL-1164, Pensacola, FL. (AD 752 032)*

Non-Additivity of Percentiles*

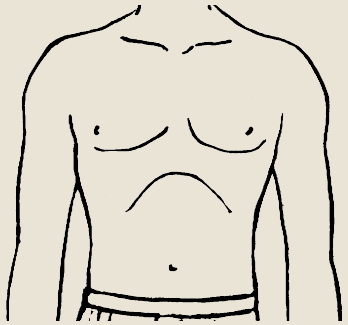


	STATURE SEGMENTS (in cm)	5%ile	Mean	95%ile
A	Cervicale to Vertex	20.8	22.91	25.1
B	Suprasternale to Cervicale	5.1	7.19	9.4
C	Acromiale to Suprasternale	-2.1	0.14	2.4
D	Bustpoint to Acromiale	10.4	13.54	16.8
E	Waist to Bustpoint	14.3	18.04	21.9
F	Abdominal Extension to Waist	4.9	7.13	9.7
G	Trochanterion to Abdominal Ext	7.1	10.48	13.6
H	Buttock to Trochanterion	-2.8	0.46	3.9
I	Crotch to Buttock	4.7	7.71	10.5
J	Gluteal Furrow to Crotch	-1.3	1.80	5.1
K	Tibiale to Gluteal furrow	26.7	30.72	34.8
L	Ankle to Tibiale	27.4	30.8	34.4
M	Lateral Malleolus to Ankle	2.4	4.41	6.8
N	Floor to Lateral Malleolus	5.8	6.77	7.8
	TOTAL OF STATURE SEGMENTS	123.4	162.1	202.2
	ACTUAL STATURE	**152.4**	**162.1**	**172.2**

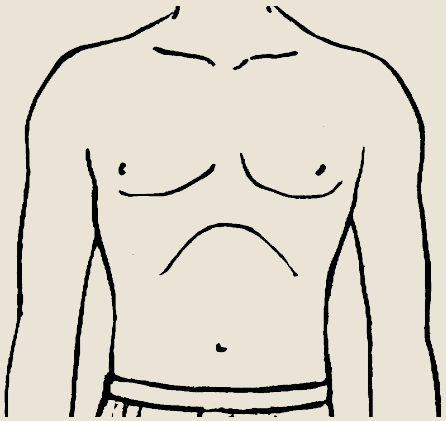
** after Churchill E (1978). Statistical Considerations. Chapter IX, NASA Reference Publication 1024, Anthropometric Source Book, Vol I. Anthropometry for Designers.*

5th/95th Percentiles Fail to Capture Shape Extremes

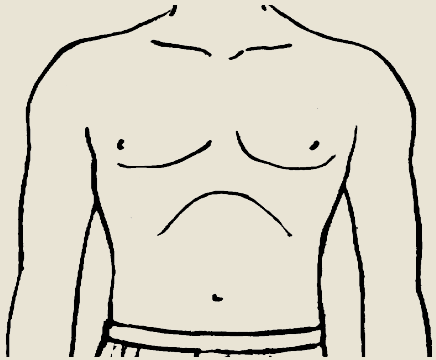
Small



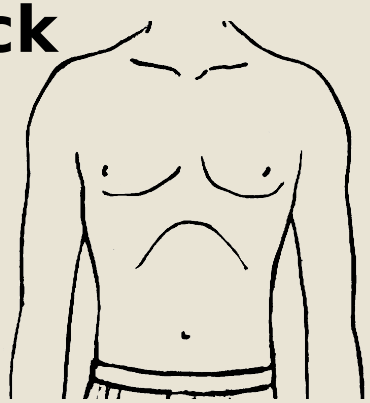
Large



Short back Large chest



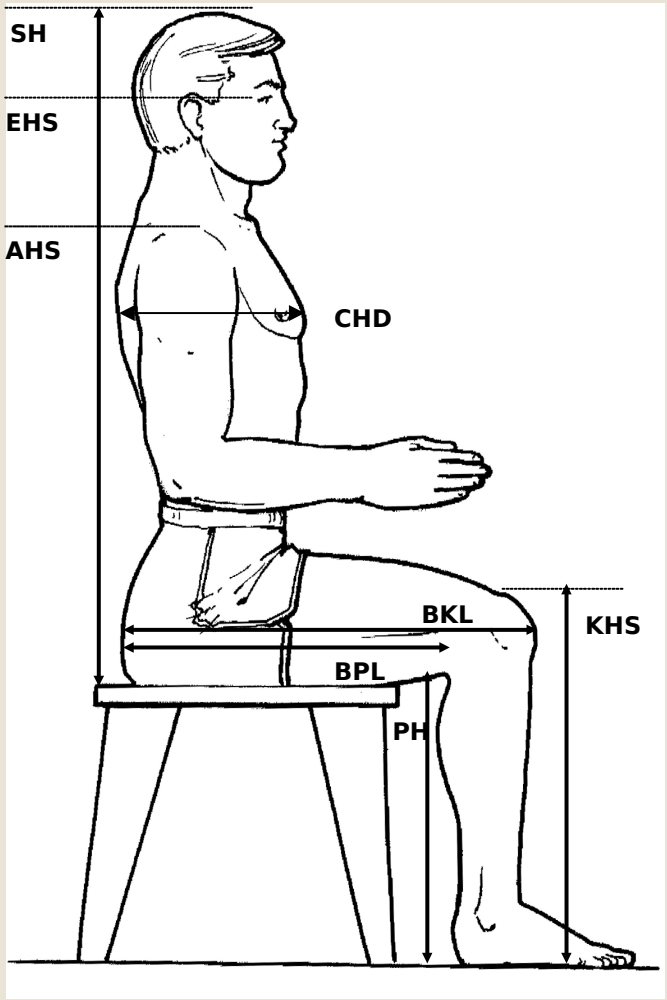
Long back Small chest



A Multivariate Alternative

- Identify those body dimensions ***critical*** to the design
- Perform a PCA on critical design variables
- Score & plot users in PCA space
- Fit an equal frequency ellipsoid to the user population distribution in PCA space
- Identify central & extreme forms on the ellipsoid
- Calculate anthropometric values of the forms or use those of actual subjects in close proximity to the forms
- Express these anthropometric models as 3D solid models or digital models

FCS Common Crewstation



AHS	**Acromion Ht Seated**
	Biacromial Breadth
BDB	**Bideltoid Breadth**
BKL	**Buttock-Knee Length**
BPL	**Buttock-Popliteal Length**
CHD	**Chest Depth**
EHS	**Eye Height Seated**
KHS	**Knee Height Seated**
PH	**Popliteal Height**
SH	**Sitting Height**
	Thumbtip Reach

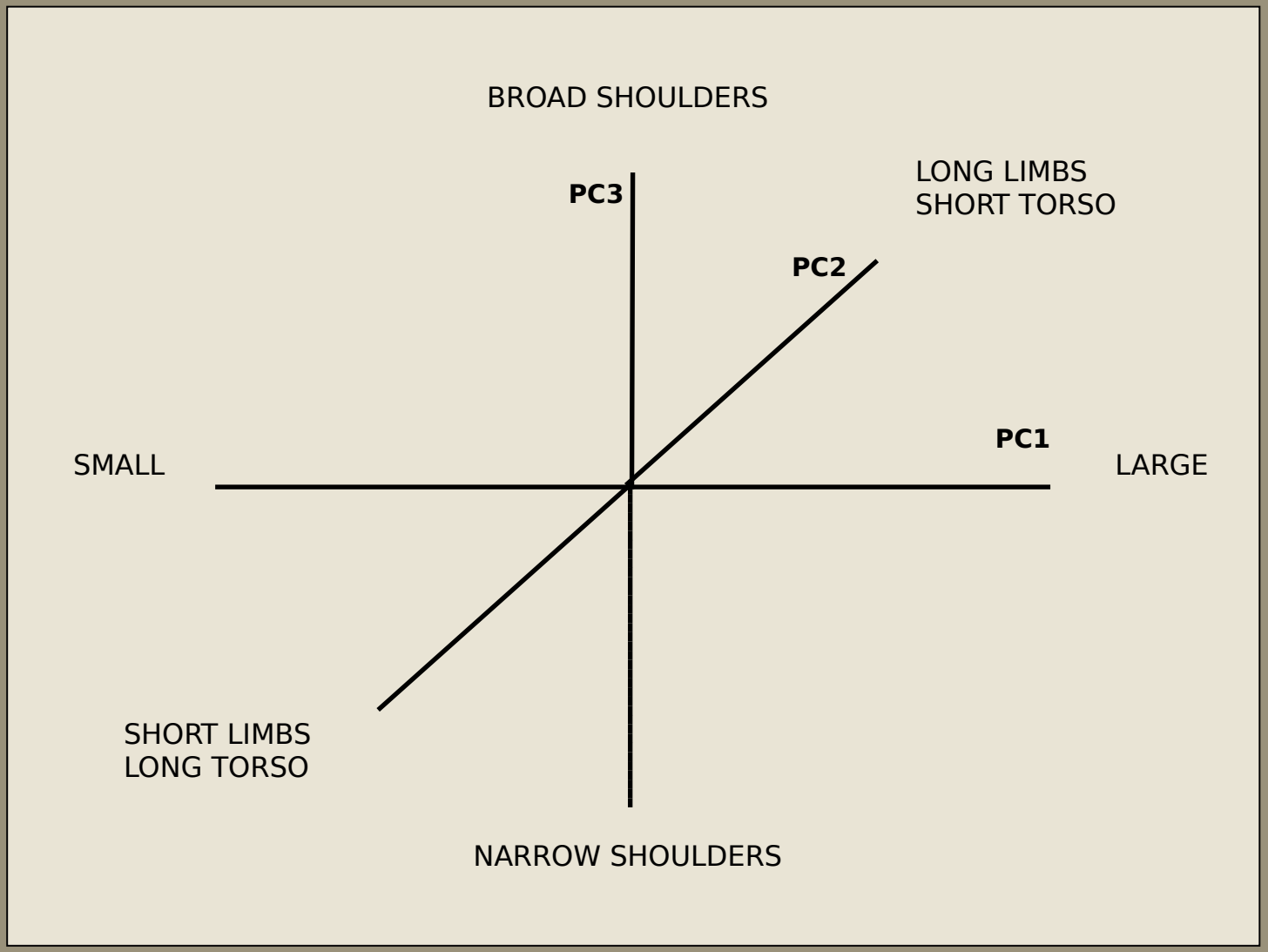
Principal Components Analysis

- ANSUR data demographically weighted; adjusted to 2015
- Sexes analyzed separately (n=3458 females, 5077 males)
- PCA conducted on the correlation matrix
- Three components retained for each sex
- The male and female PC models each explain 91% of original variation

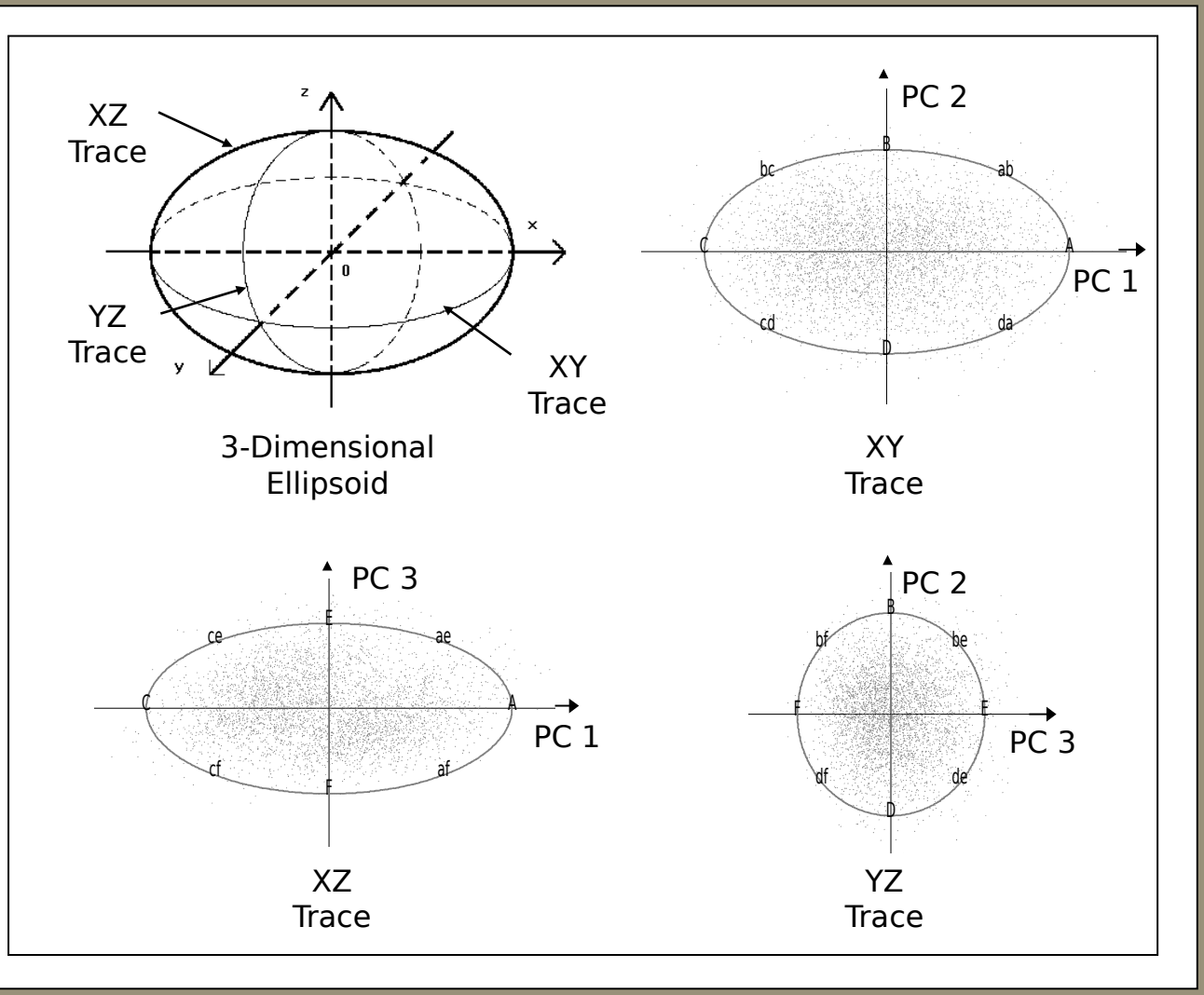
Male PCA for FCS Crewstations

Component	Eigenvalue	Difference	Proportion	Cumulative
1	4.15553	2.63386	0.5936	0.5936
2	1.52167	0.83027	0.2174	0.8110
3	0.69141	0.43125	0.0988	0.9098
4	0.26016	0.05107	0.0372	0.9470
5	0.20909	0.06813	0.0299	0.9768
		PC1	PC2	PC3
Acromion Ht Seated		0.38654	-0.41061	-0.17926
Biacromial Breadth		0.29455	0.17424	0.92279
Buttock-Knee Length		0.37039	0.40612	-0.15846
Eye Height Seated		0.41363	-0.40743	0.01650
Popliteal Height		0.37699	0.36758	-0.25946

Understanding the PCA

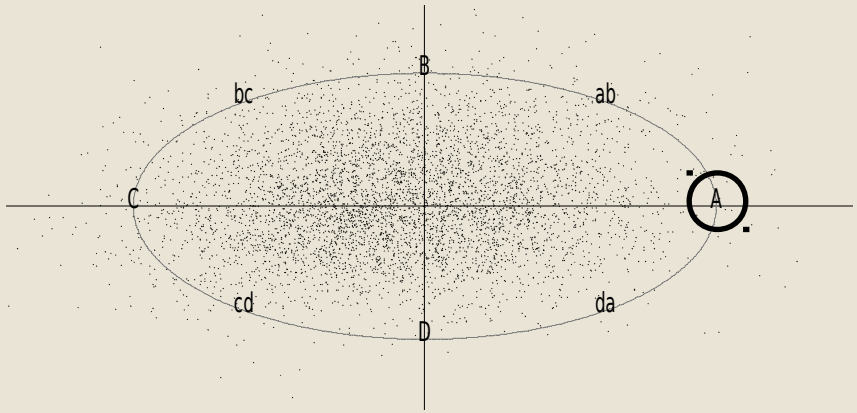


Defining Extreme Forms



Model Specifications

subno	distance
23423	0.162
14423	0.517
1498	0.616
10067	0.661
19425	0.759
23262	0.774
20849	0.780
414	0.823
1493	0.844
7173	0.862
23594	0.867
4256	0.934
21101	0.937
16867	0.964



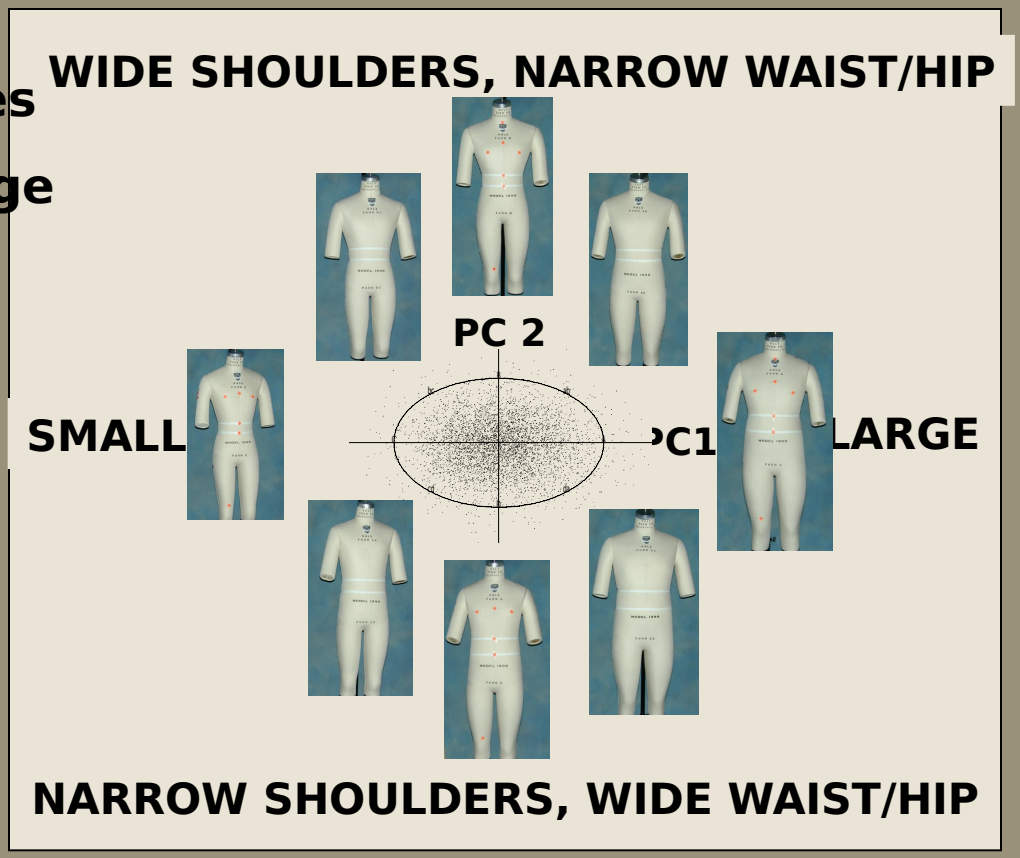
	model	median	min	max
ACRHTST	662	656	642	674
BCRMBD	426	429	419	439
BUTTKLT	677	667	647	699
EYEHTSIT	872	863	847	895
POPHGHT	487	482	461	503
SITTHGHT	998	997	975	1023
THMBTPR	882	877	846	909

How are the PCA Models Used?

- **Central Forms**
  - Represent multivariate center of the distribution of critical dimensions
  - Optimal center for both sizing systems and equipment adjustments
  - Starting point for concept development and component integration
- **Boundary Forms**
  - Represent worst case scenarios of size ***and*** shape
  - Establish limits of sizing systems & ranges of adjustment
  - Establish the body dimension ranges required of test subjects
- **Distributed Samples from within the Ellipsoid**
  - Virtual fit testing
  - Sampling strategies for test subjects

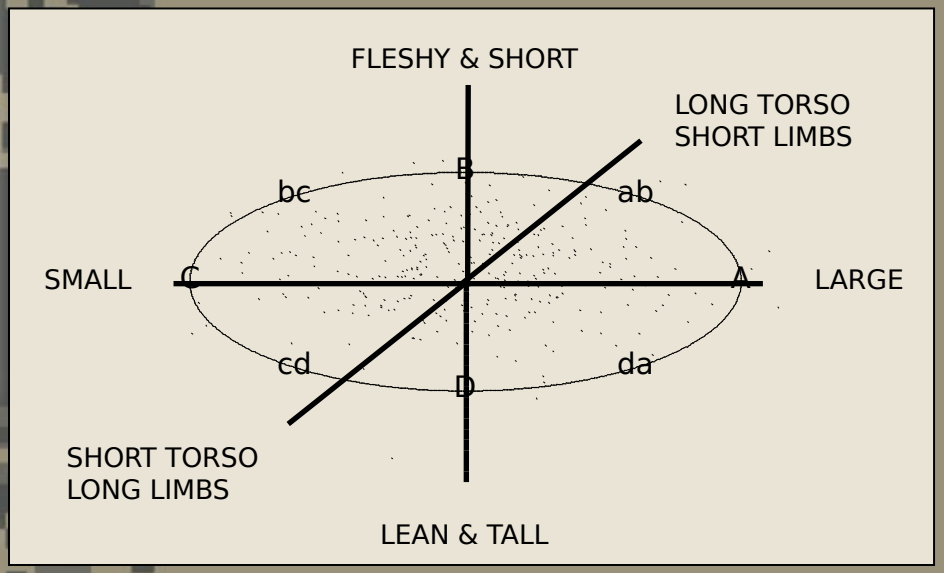
Physical Models: Manikins

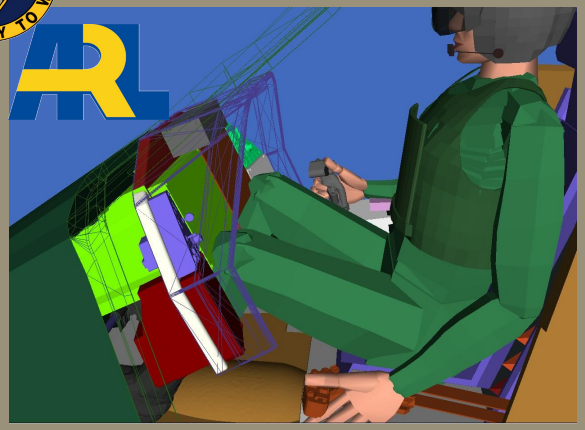
- **Worst Cases for 90% users**
- **Parachute Harnesses**
- **Body Armor Coverage**
- **~~Scanner validations~~**



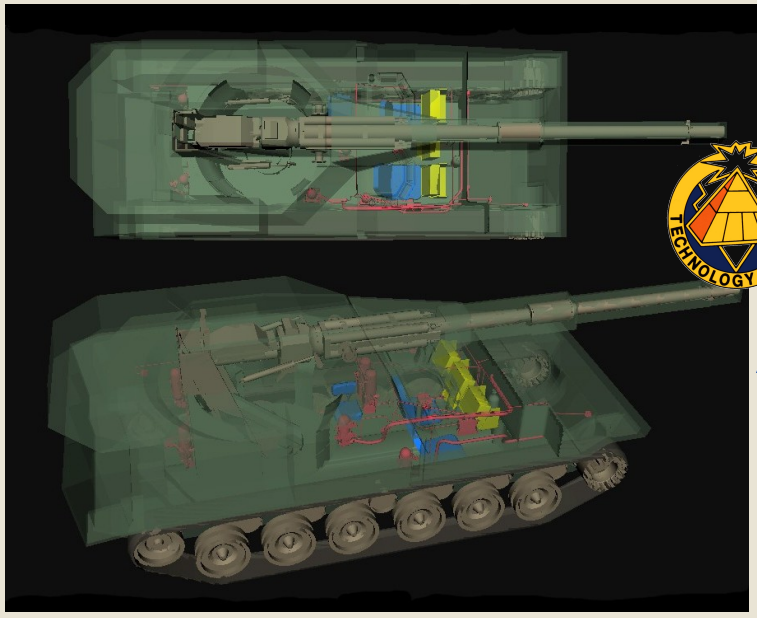
Patent # 6438853

Crewstation Design & Modeling





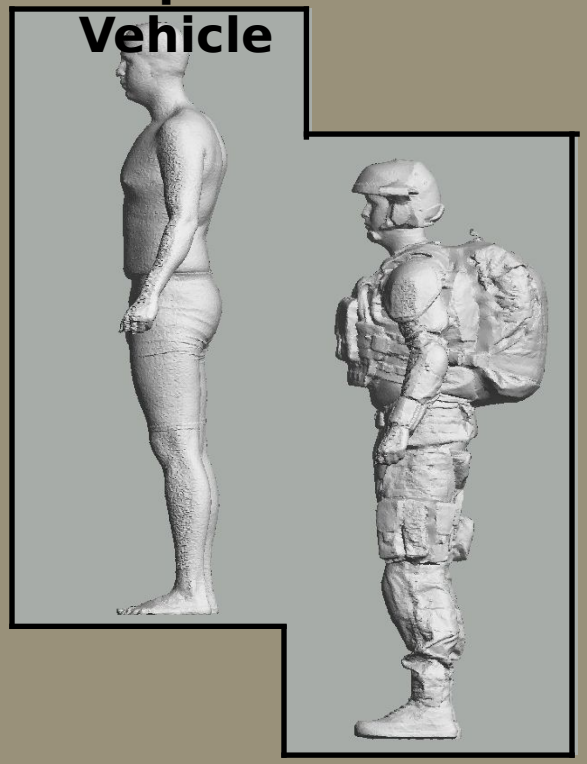
FCS Modeling



Mounted Combat System

FFW Modeling

- **FFW Sizing & Design Support**
- **Clothed Anthropometry for Digital Models**
- **Space Claims for Infantry Carrier Vehicle**



Advantages of the PCA Method

- **Direct relationship between rate of accommodation desired and models used for design & testing**
- **Shape extremes are addressed directly**
- **Boundary Forms have realistic body proportions**
- **Enables a powerful synergy between multivariate statistics & 3D technologies to optimize design & sizing**

Methodological Remarks

- Requires relatively large sample sizes, access to individual data
- Methodological decisions critical to technique success require sophisticated knowledge of human variation and its application to sizing and design
- Central & Boundary form information alone is not usually sufficient to optimize an ergonomic design, which can be misleading to naïve users
- In short, this is a method best used by experts

For Further Information

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For Further Information

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